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The Air Force has spent the past 20 years engaged in multiple combat operations and is utilizing an aircraft fleet that averages nearly a quarter of a century in age with some planes in the inventory dating back to the 1950s. The current fleet, whose planes are more than 23 years old on average, is the oldest in USAF history. Aging legacy aircraft will likely drive sustainment costs ever higher in the coming years; improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet.

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Strategies to Sustain an Aging Fleet

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MASTER OF MILITARY STUDIES

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EXECUTIVE SUMMARY

Title: Strategies to Sustain an Aging Fleet

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Thesis: Aging legacy aircraft will likely drive sustainment costs ever higher in the coming years; improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet to ensure the Air Force maintains global air superiority in the Twenty-First Century.

Discussion: The Air Force has spent the past 20 years engaged in multiple combat operations and is utilizing an aircraft fleet that averages nearly a quarter of a century in age with some planes in the inventory dating back to the 1950s. The current fleet, whose planes are more than 23 years old on average, is the oldest in USAF history. The Air Force has entered a time of reduced recapitalization for aircraft that will drive the Air Force toward retaining many of its aircraft beyond their original design service lives. To remain the world's number one Air Force, government and military leaders will need to address recapitalization of the fleet. However, age-driven cost increases may force reductions in procurements, which may further increase fleet ages, in turn forcing still further reductions in procurements creating a self-destructive downward spiral in modernization. The issue of how aging affects cost and readiness is of central concern to the Air Force, and an understanding of aging effects is imperative as the Air Force relies increasingly on older systems. The most obvious problem associated with aging fleet is that old airplanes break more often and eventually are no longer airworthy. In the years since Desert Storm the average age of the Air Force fleet has increased by nearly a decade and the availability rate has dropped in a corresponding fashion. No single strategy will solve the Air Force's challenge in dealing with an aging fleet. In fact, the Air Force already has initiatives under way to modify the existing fleet and introduce new maintenance practices. However, improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet.

Conclusion: By implementing an analytically-based parts forecasting system utilizing part tracking, field history, and reliability data parts availability will improve. Additionally, science and technology can help reduce the time to gather configuration and maintenance data from aircraft coming to depot, to rapidly determine the damage state of the aircraft in depot, and to produce replacements for obsolete parts. Finally, emulating commercial airline practices can aid in increasing aircraft availability and restraining cost growth. These strategies can be used to maintain an aging fleet and provide mission capable aircraft to operational wings to enable the United States Air Force to sustain its war fighting capability.

DISCLAIMER

Illustrations

Page

Chart 1: USAF Recapitalization Diminishing 4

Figure 1: Maintenance Man/Flight Hours as Aircraft Age 7

Chart 2: USAF O&M Costs and Totally Aircraft Inventory 8

Appendix 1: United States Aircraft Date of First Flight 24

Table of Contents

Page

EXECUTIVE SUMMARY II

DISCLAIMER III

LIST OF ILLUSTRATIONS IV

TABLE OF CONTENTS V

PREFACE VI

INTRODUCTION 1

HISTORICAL PERSPECTIVE 1

REDUCED FLEET RECAPITALIZATION 2

AIRCRAFT AGING DEFINED 6

EFFECTS OF AGING AIRCRAFT 6

AIRCRAFT AVAILABILITY CHALLENGE 9

AIRCRAFT SUSTAINMENT ISSUES 11

COMMERCIAL AIRLINE VS. USAF AIRCRAFT PRACTICES 13

STRATEGIES TO FURTHER THE LIFECYLE OF AN AGING FLEET 17

IMPROVED AIRCRAFT PARTS FORECASTING 17

AIRCRAFT MAINTENANCE SCIENCE AND TECHNOLOGY 19

INCORPORATE COMMERCIAL AIRLINE MAINTENANCE PRACTICES 20

CONCLUSIONS 23

NOTES 25

BIBLIOGRAPHY 30

PREFACE

I decided to do my research topic on the challenge of aging aircraft in the United States Air Force. With reduced budgets and continuing threats in the world, sustainment of an aging fleet is necessary. The logistics and operations community will need to develop strategies to meet this challenge. The research offers some options to consider.

I would like to express my appreciation to my military faculty member, Lieutenant Colonel Joseph Cross, and my civilian faculty member, Dr. John Gordon, whom was always willing to provide assistance throughout this process. A special thank you to Colonel Jim Howe, Air Mobility Command A4M and his team, who provided critical perspective and background. I would like to express my appreciation to my faculty mentor, Dr. Douglas Streusand, whose expert advice, tireless assistance, and meticulous attention-to-detail made this effort possible. Additionally, I would like to thank the library staff for the assistance they give to all the students of Marine Corps University. Finally, I want to thank my wife, Cynthia, who continues to provide unwavering support.

INTRODUCTION

As the United States is ending its involvement in two wars, the threats of the Twenty-First Century remain. Whether deterring potential aggressors, gathering intelligence, supporting humanitarian relief operations, or striking strategic targets, the United States Air Force war fighting capabilities are unrivaled. However, this preeminence cannot be taken for granted. The Air Force has spent the past 20 years engaged in multiple combat operations and is utilizing an aircraft fleet that averages nearly a quarter of a century in age with some planes in the inventory dating back to the 1950s.[1] The current fleet, whose planes are more than 23 years old on average, is the oldest in USAF history. Current plans forecast keeping portions of some existing fleets for as long as 80 years of service.[2] Improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet to ensure the Air Force maintains global air superiority in the Twenty-First Century.

HISTORICAL PERSPECTIVE

The problem of aging aircraft is not new and has been challenging the Air Force for decades. In 1964, then Chief of Staff of the United States Air Force General Cutis LeMay remarked, "the B-52 is going to fall apart on us before we can get a replacement for it. There is serious danger that this may happen to us."[3] Despite these concerns at the time, the B-52s remain in the Air Force's inventory today. Since the founding of the Air Force in 1947, the service has routinely had aircraft designs in operation older than the service had forecasted. Aircraft designs in operation in the 1960s were generally older than those of the 1950s; aircraft designs in operation in the 1970s were generally older than those of the 1960s; and so forth. According to a RAND study titled, *United States Air Force Aircraft Fleet Retention Trends, A Historical Analysis*, a similar pattern has continued through the present.[4] By and large, the Air

Force has had ever-aging aircraft designs in operation since its inception as an independent military service.

Over the USAF's short history, user requirements, changes in threats, obsolete technology, and theater demand were primary drivers of weapons system replacement decisions. However, age has recently become one of the most important concerns facing the Air Force. Throughout the Cold War, when the force-structure and force-age profiles were roughly constant, Air Force planners and programmers could rely on the retirement of older aircraft to free up maintenance funds. However, relying on retirement is no longer a part of current plans for the force structure. Instead, some aircraft fleets will have unprecedentedly long service lives. The zero-growth forecasting of maintenance-related budget requirements beyond the next year or two underestimates future maintenance requirements, often substantially. Those longer-term maintenance budget shortfalls can be resolved only by reprogramming funds from other initiatives or accepting decreased aircraft availability for operations and training.[5]

REDUCED FLEET RECAPITALIZATION

The Air Force has entered a time of reduced recapitalization. If the USAF wished to modernize its fleet by replacing each aircraft every 20 years, as it did in the 1970s, it would need to acquire about 315 aircraft per year. Unfortunately, the unit cost of modern aircraft has increased substantially. For example, a KC-135 tanker built in the 1950s and 1960s cost about $40 million in today's dollars, whereas a replacement aircraft would cost about $125 million for the unmodified airframe alone.[6] In addition, the Air Force's total budget has declined largely through reductions in total force size and in the number of bases. However, it has proven exceedingly difficult to reduce Operations and Maintenance (O&M) and Personnel budgets in proportion to the force structure. Whereas Research, Development, Testing and Procurement budgets constituted about half the total Air Force budgets in the 1980s, they are now less than a third.[7]

As a consequence of rising unit costs and declining budgets during the 1990s, the Air Force had found it necessary to slow the rate at which it replaced older aircraft. In the 1980s, the service was able to acquire an average of about 270 aircraft per year; in 2001, the Air Force only acquired 63 aircraft.[8] Such a reduction obviously reduces annual procurement expenses; however, it requires that the Air Force retain at least some of its fleets for a longer time. At the rate of just 63 aircraft per year, the Air Force would need about 100 years to replace every aircraft in its current fleet just once. To reduce the average aircraft age, former Air Force Chief of Staff, General Norton Schwaltz (retired 2012), stated the Air Force would have to procure 200 new aircraft per year, approximately 90 more than the service's typical annual purchase.[9] Although current plans call for increasing aircraft procurement rates over the next several years, the planned rates do not approach these levels.

To remain the world's number one Air Force, government and military leaders will need to address recapitalization of the fleet. The Air Force's mission is to fly, fight and win in air, space, and cyberspace.[10] However, age-driven cost increases may force reductions in procurements, in turn creating a self-destructive downward spiral in modernization.

Many defense experts and senior military leaders believe the US military is in a defense spending "death spiral" that threatens to reduce the effectiveness of the Air Force and other services.[11] Decisions over the last decade and a half to reduce purchases of new equipment have left the Air Force with aging fleets that are increasingly expensive to maintain. This situation creates the spending "death spiral," a cycle in which older equipment requires more funds to maintain, which decreases the funds available for new weapon systems. The Congressional

Budget Office estimates spending on O&M for aircraft increases on average by one to three percent for every year of age.[12] For example, in 2003 the Air Force spent over $2 billion to maintain approximately 660 KC-135s. This increase in maintenance was $20 million kept from other desirable programs.[13] As aircraft continue to age, the Air Force cannot afford to replace them in large enough numbers to bring down the age of the overall fleet.

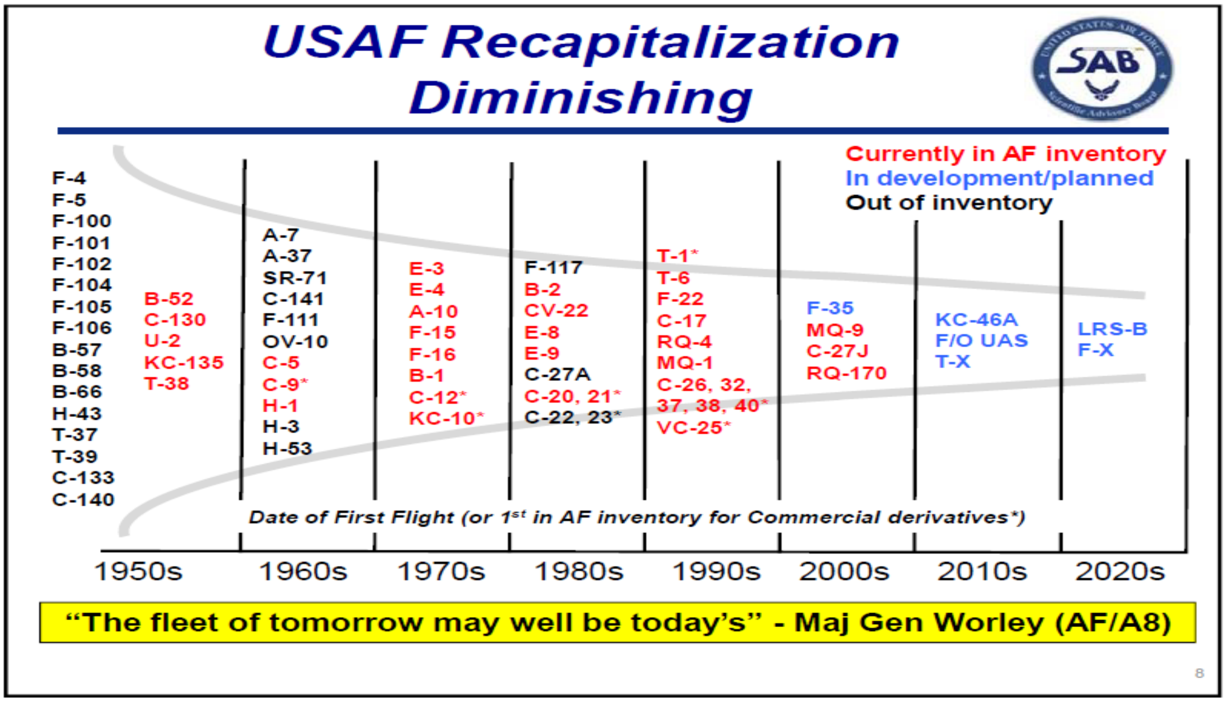

Chart 1: United States Aircraft Date of First Flight.
Source: Elizabeth Arledge, "AF/A4L Perspective on Sustainment of Aging Aircraft. Briefing, SAA Study Panel of the AF SAB during the SAB Winter Board Meeting."

The above chart from the United States Air Force Logistics section displays a snapshot of the inventory of aircraft in the Air Force fleet arranged by the date of first flight.[14] Most notable on this chart are the number of aircraft types no longer flown, and the number of aircraft currently flying that were first flown between 1950 and 1980. Some of these aircraft flown several decades ago are still in production, such as the C-130. Many of these aircraft are at least 30 years old and are projected to remain in service beyond 2040. It seems certain that the aircraft flying will need to remain for decades longer if the Air Force structure is to be maintained similar to its current size. This led to Major General Robert Worley's words to the Air Force Scientific Advisory Board, "the fleet of tomorrow may very well be todays." [15] Even the USAF's newer aircraft are projected for lengthy service. For example, the B-2 is currently projected to retire in 2058 (see Appendix 1).[16]

An important conclusion to be drawn from Chart 1 and Appendix 1 is the number of aircraft being planned for recapitalization is far fewer than those in today's inventory. The Department of Defense Congressionally mandated 30-year fixed-wing aircraft investment plan indicates the following:

- There will be a hiatus of at least 10 years in production of new strategic airlifters and long-range bombers.
- The C-17 airlifter is to undergo significant service life extension programs beginning late this decade.
- The KC-46A is the only new airplane procurement though 2025.
- The United States Air Force will buy less than a dozen tactical transports per year on average (for example, C-130J and C-27J).
- As currently planned, the projected F-35 buys build slowly and level off, not meeting required force levels until 2035.
- Replacement of E-3 Airborne Warning and Control System, RC-135 Rivet Joint, and E-8 Joint Surveillance and Target Attack Radar System will be in the far term; however it is possible that advances in Unmanned Aerial Systems will affect replacement strategy for those systems.[18]

Simply, as the Air Force recapitalization process continues to be extended, sustainment of existing aircraft is increasingly expensive. Furthermore, mission demands are not static. Both peer and non-peer threats continue to develop and challenge United States interests, driving the need for USAF capability improvements and sustainment. The government's funding process exacerbates the situation. It favors a shorter period of performance associated with legacy modernization as opposed to the consistent longer term investment support required by recapitalization.[19]

AIRCRAFT AGING DEFINED

As the Air Force relies on sustaining and modernizing aging aircraft to constitute the bulk of its fleet, it must confront the issue of how aging drives costs. There are two distinct types of aging: chronological aging and cyclic aging or usage. Chronological aging is driven by multiple temporal factors, such as: system obsolescence, problems related to corrosion and environmental degradation at the basing location, and wear. Cyclic aging is driven by the way in which the aircraft is operated or used, such as fatigue cycles and stress damage. Both of these aging modes impact the rising O&M costs as the aircraft age. Besides costs, aging also results in lower aircraft availability. More frequent breakdowns, longer repair times, higher workloads, and a shrinking workforce all result in decreasing aircraft availability.[20]

EFFECTS OF AGING AIRCRAFT

An early and influential RAND study was chaired by Mr. Raymond Pyles. He reviewed Planned Programmed Depot Maintenance (PDM) historical cost growth and analyses of engine life-cycle costs for the KC-135, 727, 737, DC-9, and DC-10. The Pyles study found a five to nine fold increase in heavy-maintenance workloads over a 40 year span.[21] The study showed that while the increase in PDM man hours varied with aircraft, the general trend was increased PDM work tasks (i.e., man hours and bill of materials) with age, with notable increases being evident after 20 years of life. This was not uniform across aircraft fleets (see Figure 1 below). Some workloads, such as fighter intermediate maintenance, grew slowly to about 18 maintenance man hours per year for a $30 million fighter flying 300 hours per year. Others grew more rapidly, such as cargo aircraft PDM to about 1,700 man hours per year for a 40 year old,

$100 million cargo aircraft. In most cases, the rate was proportional to the aircraft flyaway cost. Thus, a $100 million cargo aircraft's intermediate maintenance would grow 60 maintenance man hours per year (compared with the $30 million fighter's 18 man hours). Using these results, the Pyles study extrapolated estimates of PDM workloads over a 70 year period. Combining these predictions with the engine-support workload, and the USAF's time-phased aircraft fleet composition plans, the study estimated annual PDM and engine-support costs through the year 2022.[22] The study indicates after an initial modest rise in annual costs over the first decade of the Twenty-First Century, there would follow a sharp increase primarily driven by increasing age of the cargo and tanker fleets.[23]

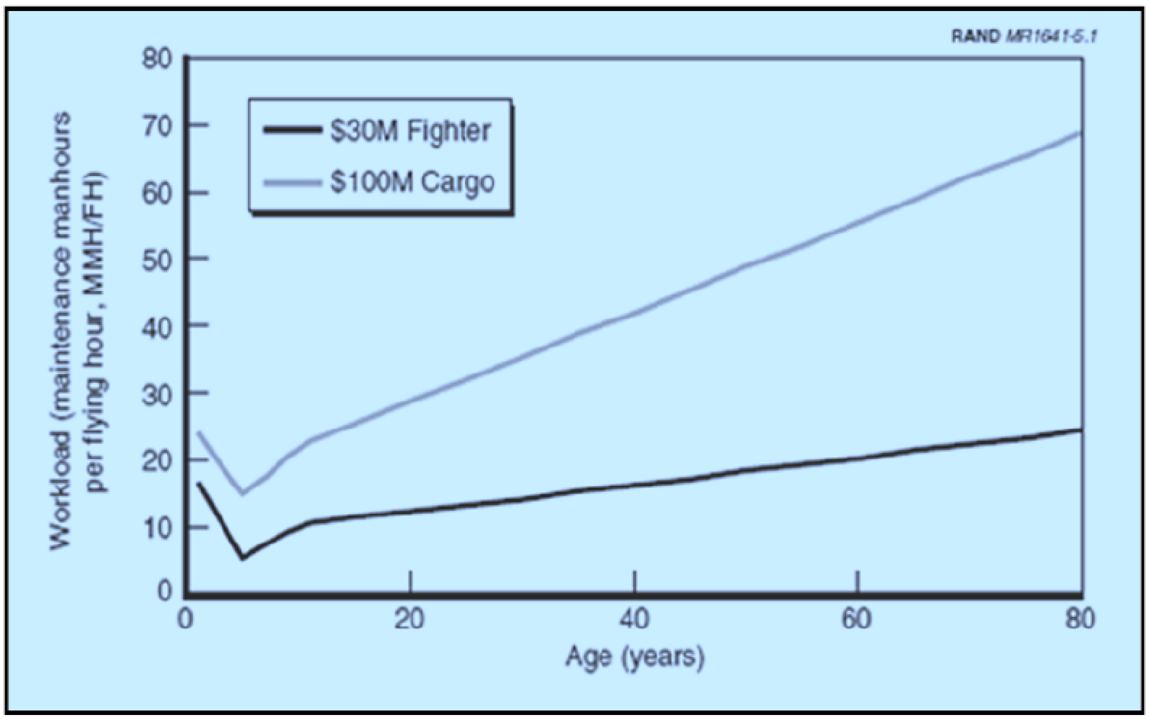

Figure 1: Maintenance Man/Flight Hours as Aircraft Age.
Source: Raymond A. Pyles, *Aging Aircraft: USAF Workload and Material Consumption Life Cycle Patterns*, (Santa Monica, CA: Rand, 2009).

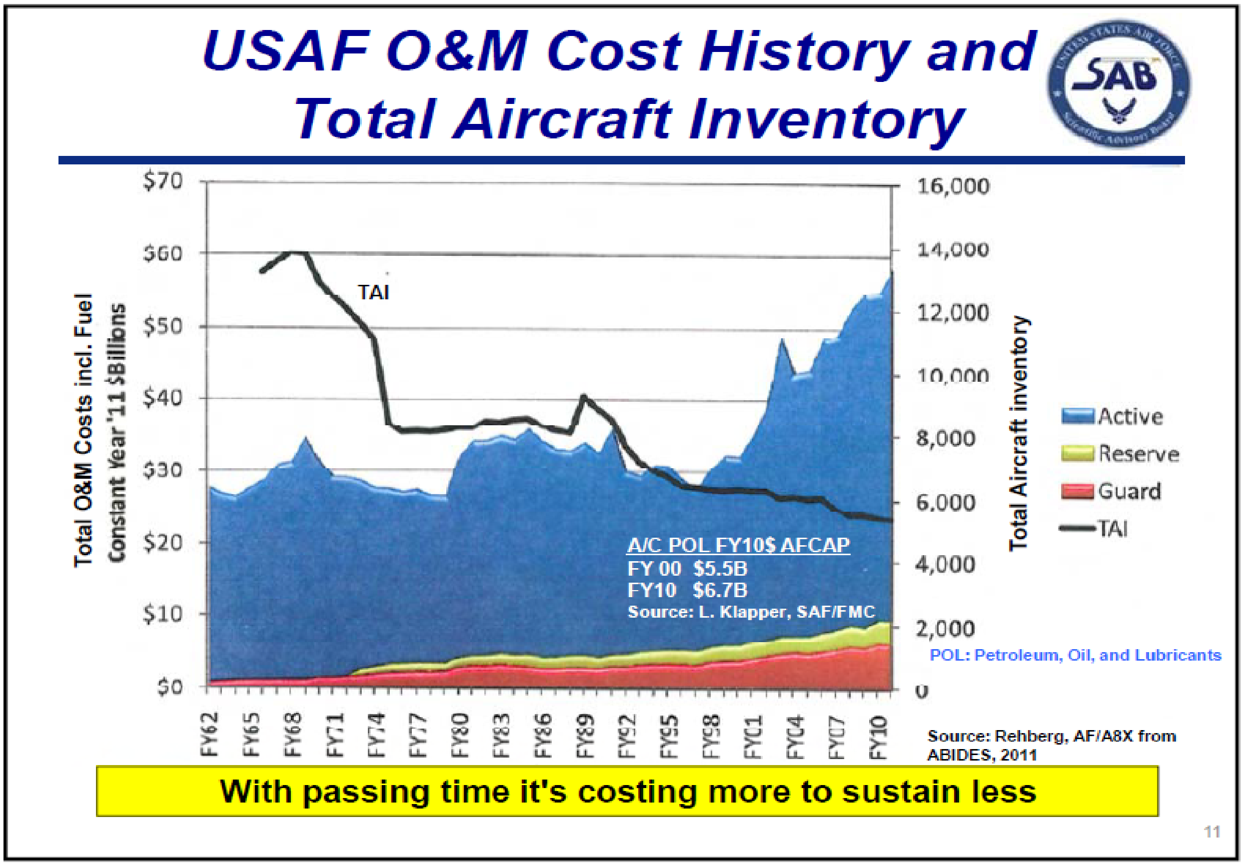

Chart 2: USAF O&M Costs and Total Aircraft Inventory.
Source: Carl Rehberg, "Examining the Aircraft Industrial Base During Declining TOA: Implications for the USAF & A Way Ahead."

Despite the USAF having less aircraft in its inventory, the costs of maintaining an older fleet continue to rise.[24] The above chart shows financial data, in government fiscal year 2011 dollars, from the USAF's Automated Budget Interactive Data Environment System from 1962 to 2010 for the O&M cost of the total aircraft fleet in inventory (TAI). While TAI has decreased dramatically over this period, the O&M costs have escalated. The decrease in TAI from 1968 to 1974 is associated with the USAF's draw down following the Vietnam War. The peak from 1989 to 1991 is associated with the President Ronald Reagan's administration build-up, followed by a continued draw down. The dramatic increase in O&M costs starting in 1998 and exacerbated after 9/11 is related to increased operational usage in the conflicts in the Middle East. As the chart indicates, fiscal year 2011 O&M costs are nearly double those in 1998 in constant dollars with 20 percent increase due to personnel costs. Additional contributing factors include increasing fuel costs and increased aircraft design complexity. In summary, the cost to maintain these aging aircraft fleets is increasing, despite the decreasing size of the total fleet, and is reflected in the overall O&M costs realized by the Air Force.[25]

AIRCRAFT AVAILABILITY CHALLENGE

The most obvious problem associated with an aging fleet is that old airplanes break more often. In the years since Desert Storm, the average age of the Air Force fleet has increased by nearly a decade, and the availability rate has dropped in a corresponding fashion. Aircraft availability is defined as the percentage of a fleet's total active inventory that is available and mission capable. This indicator is the cornerstone for maintenance metrics. It measures the ability of the maintenance group to provide sufficient aircraft to accomplish mission requirements. A set percentage of the aircraft must be available on any given day in order to execute the flying program.[26]

Aircraft availability requirements are established by the Lead Major Commands in order to fill the mission plans of the Combatant Commands. Aircraft availability is used in Weapon Systems Reviews at the Chief of Staff of the Air Force level annually and representative of PDM maintenance, reliability, and maintainability of each aircraft. However, metric reviews are different at the individual operational wings. The primary metric reviewed at operational wings is mission capable rate. Mission capable rate is the percentage of the wing possessed aircraft that are mission capable.[27] These rates take in consideration the amount of aircraft non-mission capable due to supply, maintenance, non-mission capable due to both maintenance and supply, grounded aircraft in the field, and aircraft at depot awaiting maintenance. All of these affect aircraft availability and negatively impact the USAF's ability to meet its availability targets.

Aggravating the aircraft availability dilemma is that the Air Force has been at war since 1991. During this span, aircraft availability has fallen from 77 percent to 65 percent. For the last twenty years, the service has had a significant forward presence in the Middle East that began with Operation DESERT SHIELD/STORM. After victory was declared in 1991, the Air Force remained in the region to enforce the northern and southern no-fly zones over Iraq, Operations NORTHERN WATCH and SOUTHERN WATCH, operations the Air Force would conduct until 2003 when Operation IRAQI FREEDOM began. Thus, the Air Force has flown combat missions continually for the last twenty two years.[28] Continuous combat mission has affected aircraft availability. In fact, General Bruce Carlson, Commander of the Air Force Materiel Command in 2009, stated that for every year an F-16 is deployed to United States Central Command, it ages between five and seven years due to the taxing nature of the mission.[29] Additionally, a 2003 RAND study, *Investigating Optimal Replacement of Aging Air Force Systems,* supports such a view. This analyst states, "evidence suggests combat activities along with increasing aircraft age drives up maintenance costs and tend to decrease aircraft availability."[30]

All fourteen aircraft types have lower aircraft availability rates than they did in 1991 and the aircraft break rate (aircraft landing with non-flyable discrepancies) and cost per flying hour have increased by 17 percent since 9/11.[31] Aside from these maintenance challenges, a number of dramatic airworthiness issues have afflicted the Air Force fleet. In 2000, the service grounded one third of its KC-135 air refueling aircraft because of a faulty flight control component. In 2004, the Air Force discovered that many of its C-130s had major cracks in their wings. In 2007, an F-15 broke in two while on a training flight due to structural fatigue. In 2008, the entire T-38 fleet was grounded for an extended period because of an aging control surface fixture. Most recently, half of the A-10 fleet was grounded due to wing cracks.[32] As the age of the fleet continues to increase, more maintenance problems and lower aircraft availability is expected.

AIRCRAFT SUSTAINMENT ISSUES

United States Air Force weapon sustainment enterprise includes the support functions for maintaining the readiness and operational capability of weapons systems, subsystems, software, and support systems. The Air Force makes it a priority to keep its aircraft operating for any mission the nation's leaders direct. These missions are determined by the number and variety of aircraft, the technology of the systems involved, and the global deployment of the fleet. Sustainment is defined as maintenance and upgrades to keeping the aircraft available and mission capable.[33] In the sustainment phase, funds are expended as the weapon system matures and is fully employed in training and operational activities. The majority of the costs in the sustainment phase are used for repair and remanufacture, and to modernize or overcome issues. For example, as aircraft ages and the lead Major Command identifies a modernization requirement, then that modernization cost would be funded by sustainment dollars.

The total cost of Air Force sustainment activities exceeded the operating costs of such industry giants as American and Delta Airlines. In addition, it accounts for nearly 70 percent of total system lifecycle cost. It is important that sustainment issues be considered throughout the life cycle, but it is crucial in the design and acquisition phases. The ability of the Air Force to keep its aircraft operating at an acceptable operational tempo is essential to fulfillment of its mission. Maintaining this capability has become much more difficult today since the Air Force has effectively been operating on wartime footing for the past 22 years.[34]

Sustaining the aircraft structure is one of the main challenges in extending use of old aircraft. An aircraft's structure or airframe includes the fuselage, wing, empennage, landing gear, control systems, engine section, nacelles, air induction, weapon mounts, engine mounts, structural operating mechanisms, and other components as described in the contract specifications as per United States Air Force standard for its Aircraft Structural Integrity Program.[35] As aircraft age and use increases, the damage accumulates in their structures and various subsystems. Various damage mechanisms, such as fatigue cracking, corrosion, and stress-corrosion cracking, contribute to the deterioration of aircraft structure. Many older aircraft are facing these aging issues, and many more aircraft are expected to encounter them as the Air Force keeps them in service longer. These increases in maintenance workload may become extremely costly and may lead to poor aircraft availability, threatening mission capabilities.[36]

The result of aircraft aging is increasing sustainment costs that include both maintenance (maintaining the existing fleet) and modernization (adding and improving the capabilities of the existing fleet against an improving set of threats). Sustainment is driven by today's needs, but in a constrained resource environment, it will be at the expense and delay of next generation aircraft. For example, the F-15, C-130, KC-135, and B-52 plan for sustainment and replacement parts was based on the original projected life of the aircraft; however, as the life of these aircraft has more than doubled, the original parts strategy has become inadequate. Additionally, as legacy aircraft sustainment technology does not change, Original Equipment Manufacturers (OEM) tends to move on to new technologies and products aligned with new procurements or upgrades. This has often resulted in the OEM, and their second and third tier suppliers, no longer being available as a supplier of replacement parts. As suppliers diminish, the sustainment enterprise relies more heavily on cannibalizing parts from grounded aircraft and on the commercial parts sector. However, commercial part lifecycles are very short compared to Air

Force aircraft lifetimes and the subsequent decrease in product lifecycle times, especially for commercial electronics, continue to contribute to the aircraft parts sustainment problem.[37]

The Air Force supply chain suffers from inefficiencies in meeting demand for parts and components. These deficiencies become more pronounced as the aircraft age and original parts suppliers are no longer in business. Operational wings are concerned with mission capable rates and ensuring aircraft are prepared for their wartime mission; however this does not always lead to maintenance activities that are value added. For example, a practice known as cannibalism is used. This involves taking parts of one aircraft to be used on another aircraft. This practice will skew the effect of age on maintenance because it may take up to twice the labor hours to use cannibalized parts as it does to use a new part. So while the downtime of an aircraft is minimized, the number of maintenance hours may be increased.[38]

COMMERCIAL AIRLINE VS. USAF AIRCRAFT PRACTICES

The Air Force and the civilian industry maintain, operate, and procure aircraft differently and have different objectives. For example, the aircraft usage patterns are different. The Air Force flies fewer hours per year than the commercial sector. Another concern is selection bias with regard to the retirement of commercial aircraft. Bias is believed to exist when airlines decide which aircraft in a fleet to sell; they may first sell their problem aircraft. Therefore, the data representing United States airlines could have represented only the best aircraft available from the manufacturer.[39] A briefing in 1998 at the Air Logistics Center in Oklahoma City summarized this problem:

> It should be recognized that selective replacement of high time commercial aircraft is a swift business decision. Typically commercial airlines have an ongoing fleet modernization program, constantly tailoring their fleet mix to present day flight routes and load factors. The military, however, cannot be as selective; they must maintain a fleet size as specified by a higher command, without the luxury to selectively retire individual high maintenance aircraft.[40]

Since commercial airlines are able to get rid of aircraft, or entire fleets, then the age effect would be biased. The Air Force does not have this option of prematurely ridding itself of a problem aircraft due to mission requirements and Congressional oversight.

Additionally, there are numerous differences between the maintenance practices used by commercial airlines and the Air Force. As discussed previously, aircraft availability means aircraft are available for a mission, whereas commercial airlines require high aircraft availability rates to meet revenue and to make profits. Basically, a plane not flying produces no value for an airline; this means a commercial aircraft average around twelve flight hours per day. These perimeters also mean there is less commercial aircraft non mission capable. Typically, between 3 and 8 percent of the aircraft at a commercial airline are out of service for maintenance at any time. This means the commercial airline aircraft availability target is greater than 90 percent.[41] The USAF's aircraft availability varied by aircraft, but typically averaged 70 to 80 percent. Additionally, several USAF's aircraft are projected to be below aircraft availability standards well into the future.[42]

Commercial airlines are very good at predicting the amount of work needed for each aircraft as it visits a depot for maintenance. This is likely due to the fact that commercial airlines are highly data focused, maintain aircraft regularly in service, track the maintenance process closely, and have highly predictable flight profiles. The Air Force does very poorly at predicting maintenance needs for its aircraft before it goes to depot maintenance. Depot maintenance contracts often contain provisions that allow contractors to perform and charge the government for additional work that could not be specifically defined at the time of contract award but may be needed as an item is being repaired. For instance, when an item is disassembled and inspected during the repair process, the contractor may discover work needed that was not spelled out by the basic contract requirements. The Department of Defense anticipates the potential for such additional work and increased costs by including clauses in its maintenance contracts referred to as “over and above” work.[43] Over and above accounts for a significant percentage of the cost and time required for aircraft depot maintenance visits and grows with aircraft age.

Commercial airlines normally have little over and above work. The commercial industry uses detailed data tracking and analysis to continuously refine the maintenance process throughout the life cycle of the aircraft. The Air Force appears to have a lower level of knowledge about the aircraft state coming into the depot than do the commercial airlines.[44] The difference lies in the data collection and analysis techniques used by both organizations. In fact, it is a common Air Force field level maintenance practice to defer some maintenance until the aircraft is in depot. The biggest issue with maintenance data collection in the Air Force is the use of numerous databases that are not easily searchable. The accuracy and validity of the data is also commonly questioned by Air Force officials.

Another difference between the commercial industry and Air Force is the amount of aircraft in depot maintenance. Commercial aircraft heavy maintenance is completed at either an airline’s internal facility or a Maintenance, Repair, and Overhaul facility.[45] The Air Force conducts its heavy maintenance at one of three depots: Warner Robins, Georgia; Oklahoma City, Oklahoma; and Ogden, Utah. Commercial airlines perform maintenance at locations and times based on the most economical opportunities. Studies show commercial airlines conduct a larger percentage of their maintenance in the field versus at a maintenance depot.[46] Another advantage the commercial industry has is that aircraft maintenance is performed with a large and experienced staff during an overnight layover. In contrast to the airlines, the Air Force prefers to minimize maintenance completed in the field and defer it until the aircraft is scheduled for a depot visit. This deferring maintenance method is used mainly due to the need for aircraft availability, experience level of field maintenance personnel, and lack of spare parts. Deferring the maintenance to the depots allows more experience mechanics to do the work and is believed to be more cost effective since the aircraft is not available for missions.

In regards to parts replacement, commercial airlines typically use a Maintenance Steering Group process to classify part criticality and use reliability data to determine maintenance replacement strategies.[47] The commercial airline's tracking and reliability data allow many of its aircraft parts to "fly to fail." The airlines also avoid delayed or cancelled flights using the Minimum Equipment List, which is a Federal Aviation Administration approved document that allows an aircraft to fly with a certain item(s) inoperative.[48] The essence of this strategy is that the aircraft can be dispatched for a limited number of flights that allows continued operation until the next maintenance visit where the failed part is then replaced.

The Air Force fleet typically has more mission critical equipment items than a commercial airline. The Air Force Minimum Equipment List policy is a pre-launch document that lists the minimum equipment and systems to operate the aircraft.[49] These lists are approved by the weapon system managers in the lead commands by both the Operation and Logistics section. Both operators and maintainers have a Minimum Equipment Lists, but they can differ. Further, the Air Force prefers to do the majority of their maintenance at the depots. This limits their ability to use the fly to fail parts replacement strategy. However, there are systems in which the strategy is used effectively, such as thrust reversers, cabin pressure controls, air turbine starters and start valves, auxiliary power units, secondary electronic devices, and valves. Not all USAF aircraft have these systems, but those that do use the fly to fail strategy.

STRATEGIES TO FURTHER THE LIFECYLE OF AN AGING FLEET

The Air Force already has initiatives under way to modify the existing fleet and introduce new maintenance practices. For example, replacement of the KC-135 fleet with the new air refueler KC-46A earlier, implement major structural upgrades for the F-16C fleet, invest in additional facilities and equipment to modernize Air Logistics Centers,[50] and upgrade all C-17 aircraft to a standard block configuration.[51] These initiatives and related efforts will help the Air Force reduce future maintenance workloads or increase its ability to absorb those workloads. Unfortunately, the Air Force has little ability to estimate how much a particular initiative may contribute to the future availability and costs of individual fleets. Improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet.

IMPROVED AIRCRAFT PARTS FORECASTING

Maintaining adequate aircraft spare parts for an aging fleet requires knowledgeable sustainment engineers, accurate parts demand forecasting, and a base of suppliers. For new aircraft, the aircraft spare parts challenge are handled by the Original Equipment Manufacturer. However, this challenge often shifts to the Air Force especially as the life of an aircraft type is extended beyond its original service life and Original Equipment Manufacturer involvement in O&M is reduced as a result of a shift towards organic sustainment.

Sustainment engineers are instrumental in developing the PDM work tasks and bill of materials. They have technical authority for analyzing alternative part and subsystem solutions as original parts encounter diminished manufacturing issues. They must consider airworthiness, maintainability, and system reliability. Often dependencies between parts or subsystems are not sufficiently documented in the Technical Order and are only understood through experience.[52] Item Managers within the Air Force Global Logistics Support Centers (AFGLSC) and Defense Logistics Agency (DLA) must maintain a viable parts listing and supplier base.

Accurate parts demand forecasting is needed to minimize aircraft down time resulting from parts unavailability. Forecasting parts demand is the responsibility of the AFGLSC and DLA with AFGLSC pulling supply requirements from the field and depots.[53] AFGLSC maintains a database of historical parts usage that is the basis for forecasting future needs over a five year time horizon. However, AFGLSC's supply chain forecast accuracy for fiscal year 2009 was less than 50 percent.[54] These part forecast challenge cannot be solely contributed to these agencies. Often forecasting errors can arise from inaccurate data supplied from the field and the numerous databases collecting information that are not linked.

Minimizing delays field level and depot maintenance due to lack of spare parts will require the Air Force to take action. As discussed in the Air Force Scientific Advisory Board study for sustaining aircraft, there is a need to improve parts tracking, field history, and reliability data.[55] Today there is no automated, or consistent, enterprise approach to capturing these data and feeding it into the D200A forecasting system. The D200A contains historical parts data from field and depot maintenance. It computes worldwide replenishment requirements for the Air Force and other services within the Department of Defense.[56] A system that ties parts data to tail number and flight history will be important for enabling more sophisticated forecasting. While some statistical analysis currently exists in the D200A, more data analysis based on predictive analytics is needed. Once the parts database includes sufficient and validated reference information such that representative models can be developed, then predictive analytics should significantly improve parts forecasting.[57]

Finally, including Reliability Centered Maintenance (RCM) in the supply chain procurement process would improve forecasting, increase system lifetime, and thereby improve aircraft availability. RCM analysis provides a structured framework for analyzing the functions and potential failures for an airplane with a focus on preserving system functions, rather than preserving equipment. RCM uses a combination of reliability data from the certification process along with a history of aircraft usage to determine the wear-out rate for each component of the aircraft.[58] This forecasting capability could be a crucial component in parts forecasting for aging Air Force aircraft. RCM typically increases maintenance parts costs since it is preventive and some components are replaced prior to failure and have useful life remaining. This cost is offset by lowered aircraft downtime due to reduced component failures in service and significant reductions in wait time for undelivered parts.[59]

AIRCRAFT MAINTENANCE SCIENCE AND TECHNOLOGY

An increase in funding for aircraft sustainment is needed. The Air Force Research Laboratory (AFRL) is the primary entity to address maintenance science and technology for the United States Air Force. But only 3.5 percent of the AFRL budget is currently devoted to overall aircraft sustainment science and technology.[60] The increasing maintenance demand of an aging fleet of aircraft combined with a reduced likelihood of introducing a significant number of new aircraft technologies, there is a need for a better understanding of aircraft sustainment science and technology. The AFRL supported research in many important aging aircraft topics, especially those focusing on corrosion, stress-corrosion cracking, and crack initiation, have been degraded or eliminated in the last few years.[61] These topics are becoming more relevant as the age of Air Force aircraft are extended beyond the age associated with their original design lives.

The Air Force Scientific Advisory Board provided key recommendations associated with increasing AFRL science and technology focus on research efforts that impact maintenance. The first recommendation is that AFRL should reallocate its portfolio of research activities to increase research and technology efforts toward maintenance technologies in order to better address the materials issues associated with aging aircraft. Second, the report states areas that are relevant to sustaining aging aircraft should be revitalized. In particular, corrosion and stress corrosion cracking are becoming increasingly important for aging aircraft, especially with recent increases in demand and deployment in harsh environments. Another example is wiring fault detection involves the daunting task of pinpointing a fault in long stretches of wire in complex wiring geometries. Developments in a variety of electronics-based efforts are required to address this issue that spans the range of aircraft. In summary, the science and technology investment in maintenance technologies has waned and must be resurrected if the Air Force is going to have the technologies required to maintain their legacy aircraft more affordably for the decades currently reflected in their plans.[62]

INCORPORATE COMMERCIAL AIRLINE MAINTENANCE PRACTICES

Commercial airlines and maintenance providers have several practices that can be incorporated in the Air Force maintenance community. One such practice is Maintenance Steering Group -3 (MSG-3). It is common practice for airlines to perform aircraft maintenance per MSG-3 practices.[63] Per *Aviation Today*, MSG-3 is the only game in town for commercial airplane manufacturers and is the only methodology accepted by the airworthiness authorities.[64]

The MSG-3 program begins as the aircraft enters service and is continually updated throughout the aircraft lifecycle. MSG-3 uses the Failure Modes & Effects Analysis technique to balance safety, schedule, and risk for the maintenance process. One of the key features of the

MSG-3 practice is that maintenance and inspections for all systems in a given area of the aircraft are made while the aircraft is open for one system maintenance action, so that all the maintenance in that area can be performed. This minimizes the number of times a given area of the aircraft must be opened up for maintenance and generally provides for longer lasting protection systems and reduced effects of aging. Data is required to make these refinements, so airlines place significant emphasis on accurate collection and analysis of the data.[65]

With declining budgets, economics is an important consideration. Using MSG-3 logic the sequence of intervention follows an order of least expensive to most expensive, in order to test the effectively of the least expensive task first. In each case the technical engineers must answer the question if the task is applicable and effective at ensuring operational safety or mitigating the consequences to an acceptable level. Structural analysis follows a similar path. A visual inspection would be the first choice to be considered, followed by a detailed inspection and then by special detailed inspection. A subtle difference with the structural analysis focuses on the deductibility of the degradation from accidental damage, environmental damage or fatigue damage.[66] Additionally, *Aviation Today* published, "commercial airlines using an MSG-3-derived program has produced savings with cost reductions in scheduled maintenance programs up to 30 percent."[67] Per Mr. Kevin Berger of Federal Express:

> MSG-3 logic is much more detailed and continues to evolve with industry experience and technology. This enables the manufacturers, operators and regulators to design, operate and insure industry safety with increasingly safer equipment and more efficient maintenance requirements. Previous approaches led to unnecessary maintenance tasks, which could induce potential damage and cause supplemental failures.[68]

Commercial airlines also utilize sophisticated tools to track the maintenance status of aircraft. For example, the Boeing Company has a 24/7/365 operations center that tracks the status of every aircraft. This facility consists of a highly automated aircraft tracking system with a large staff to monitor status and resolve issues. Analysts can easily access maintenance information for any aircraft tail number. Service requests are recorded, promise dates committed, and metrics tracked to ensure on-time closure of issues.[69] The Air Force does not have these tracking tools. This can lead to inefficiencies in the supply chain enterprise which leads to ineffective parts forecasting. Part of this problem is the large number of independent databases used by Air Force in tracking its aircraft, their configurations, their maintenance actions, and the parts used for maintenance. Currently there are 16 different databases contributes to the supply chain enterprise. The Air Force would benefit from developing a software database structures that allow read and search capability for all the databases used by each aircraft. The ability to remove redundancy in Air Force databases, provide better cataloguing of the parts and components they order, and have a more accurate assessment and forecast of the needs for each type of aircraft.

The commercial airlines also make significant efforts to perform maintenance at the most economically advantageous location. For example, significant commercial aircraft maintenance is performed during overnight layovers using surge maintenance crews that perform the work within eight hours or less. This practice allows the airlines to complete required maintenance while maximizing aircraft availability. Commercial airlines centers place a high emphasis on rapid completion of major overhauls. For example, a wide body aircraft major overhaul will be completed in 45 days or less and narrow body overhauls are typically completed in 14 days or less.[70] This rapid turnaround is essentially to the commercial airline industry since so the aircraft can produce revenues. The Air Force could benefit from a centralized maintenance tacking and scheduling approach, especially in the airlift and tanker communities. Instead of delaying scheduled maintenance until an aircraft returns to its home station, an aircraft could be scheduled for maintenance downtime at the most advantageous location. However, this would take centralized databases, robust parts supply at key locations, and operations community buy in since the aircraft's crew is sometimes assigned to a particular tail number, especially with Guard and Reserve personnel. This concept would take the operations and logistics community working together, with centralized tracking and scheduling systems, to make it feasible.

CONCLUSION

It is critical for the Air Force to become as efficient as possible in maintaining and upgrading aging aircraft in order for them to remain viable members of the USAF fleet. Aging legacy aircraft will likely drive sustainment costs ever higher in the coming years; improved aircraft parts forecasting, increased aircraft maintenance science and technology funding, and incorporating commercial airline maintenance practices are strategies the Air Force should examine in sustaining an aging fleet to ensure the Air Force maintains global air superiority in the Twenty-First Century.

By implementing an analytically-based parts forecasting system utilizing part tracking, field history, and reliability data parts availability will improve. Additionally, science and technology can help reduce the time to gather configuration and maintenance data from aircraft coming to depot, to rapidly determine the damage state of the aircraft in depot, and to produce replacements for obsolete parts. Finally, emulating commercial airline practices can aid in increasing aircraft availability and restraining cost growth. These strategies can be used to maintain an aging fleet and provide mission capable aircraft to operational wings to enable the United States Air Force to sustain its war fighting capability.

Appendix 1

Aircraft Type	DSL (hrs)	CSL (EFH)	RSL (EFH)	Number of Aircraft	Average Age Now	Projected Retirement	Age at Retirement
A-10	6,000	See Note	16,000 EFH	347	29.3	2040	59.3
B-1	9,681	14,522	NA	66	23.1	2040	52.1
B-2	10,000	20,000 AFH	NA	20	16.2	2058	64.2
B-52	5,000	27,700 AFH	NA	76	48.8	2040	~79
C/KC-135 R/T	NA	39,000 AFH	NA	417	49.1	2045	84 years
C-130E	NA	38,000 EFH	NA	46	47	2012	49
C-130H	NA	38/60,000 EFH (based on Wing)	NA	268	24	*	*
C-130J	NA	38/60,000 EFH (based on Wing)	NA	68	4.7	*	*
C-5A/C	30,000	47,200 EFH	NA	59	38.9	2011 - 17 2012 - 5 2040 - 37	39.5 40.5 68.5
C-5B/M	30,000	52,500 EFH	NA	44/6	22.7/26.1	2040	54
C-17	30,000	45,000 EFH A/C Structure	NA	206	8.1	2028	26.1
E-3	30,000	30,000 EFH	NA	23/9	32.1/27.5	**	**
F-15 A/C/D	4,000	9,000 EFH	14,250 EFH	250	26.8	2025**	41.8
F-15E	8,000	8,000 EFH	16,000 EFH	222	18.8	2035**	43.8
F-16 C/D	block dependent	block dependent	block dependant	1023	20	2026	36.3
F-16 Blk 30/32	8,000 (Goal)	10,800 EFH	10,800 EFH	317	22.5	2014-2025/2025	38/43
F-16 Blk 40/42	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	395	19.9	2016-2025/2020	35/40
F-16 Blk 50/52	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	245	15.6	2020-2030/2026	36/37
F-22	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	166	3.6	2033-2049	27-34
KC-10	60,000	60,000 EFH		59	25.7	2042	57.7
EC-130H	NA	38,000 EFH	NA	14	37.3	2035	62
AC-130H	NA	38/60,000 EFH (based on Wing)	NA	8	41.0	2018	48
T-38	7,000	See Note	NA	494	43.5	2026	~60

Table 1. Average Aircraft Age (as of 2011) and Projected Age at Retirement. *Source*: United States Department of Defense, *Aircraft Procurement Plan Fiscal Years (FY)2012-2041* (Washington, DC: United States Air Force, March 2011).

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